PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 3 : F02B 53/00

A1

(11) International Publication Number: WO 83/ 01276

(43) International Publication Date: 14 April 1983 (14.04.83)

(21) International Application Number: PCT/US81/01337

(22) International Filing Date: 2 October 1981 (02.10.81)

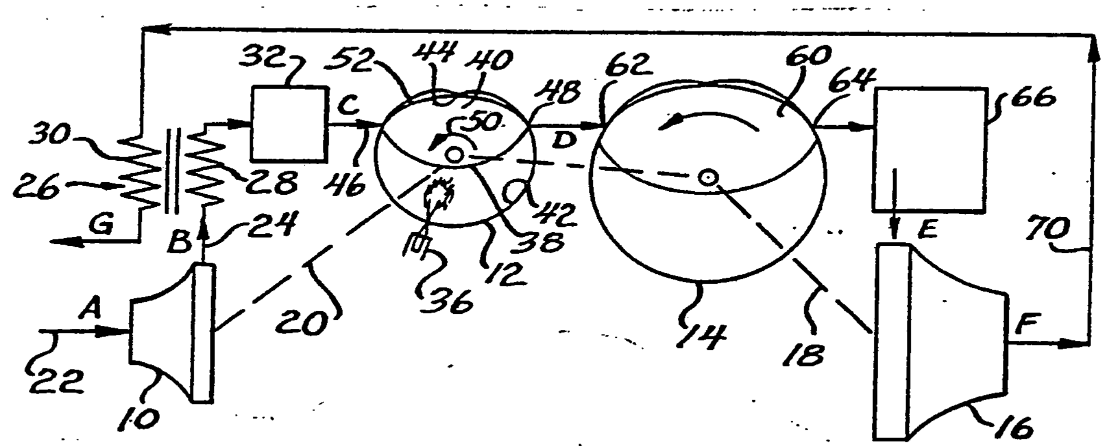
(71)(72) Applicants and Inventors: CLARKE, John, M. [GB/US]; 13609 Luscern Street, Dunlap, IL 61525 (US). GOLOFF, Alexander [US/US]; 110 East Oakwood Road, East Peoria, IL 61611 (US).

(74) Agents: WATTS, Loyal, O. et al.; 100 Northeast Adams Street, Peoria, IL 61629 (US).

(81) Designated State: US.

Published
With international search report.
Upon request of the applicant under article 64(3)(c)(i).

(54) Title: COMPOUND POWER PLANT WITH EFFICIENT HEAT CYCLE



(57) Abstract

A compound engine type power plant with high thermal efficiency and high power output including a compressor (10), a positive displacement combustor (12) for adding heat to a compressed working fluid at constant volume, and an expander (14, 16). The expander is a two stage expander employing a positive displacement expander (14) as the first stage and a turbine (16) as the second stage. Heat may be added to increase the temperature of the working medium at the combustor (12) to a level well in excess of that which could be tolerated by a turbine type expander alone to thereby increase operational efficiency and power output.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria
AU	Australia
BE	Belgium
BR	Brazil
CF	Central African Republic
CG	Congo
CH	Switzerland
CM	Cameroon
DE	Germany, Federal Republic of
DK	Denmark
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
HU	Hungary
JP	Japan
KP	Democratic People's Republic of Korea
LI	Liechtenstein
LK	Sri Lanka
LU	Luxembourg
MC	Monaco
MG	Madagascar
MR	Mauritania
MW	Malawi
NL	Netherlands
NO	Norway
RO	Romania
SE	Sweden
SN	Senegal
SU	Soviet Union
TD	Chad
TG	Togo
US	United States of America

Description

Compound Power Plant With Efficient Heat Cycle

Technical Field

This invention relates to a highly efficient power plant which operates on what is basically an Atkinson cycle.

Background Art

Modern day engines or power plants generally operate under conditions approximating one of three major thermodynamic cycles. Most spark ignition, positive displacement engines, operate on the so-called "Otto" cycle while most compression ignition, positive displacement engines operate on the so-called "Diesel" cycle.

Turbine engines operate on the "Brayton" cycle in which heat is added to the working fluid at constant pressure.

Each of these cycles has a certain theoretical efficiency which is dependent upon design parameters associated with the particular mechanism involved. Each of the foregoing cycles also has points of inefficiency which may arise out of either theoretical or practical considerations.

For example, in the case of the Otto or Diesel cycles, isentropic expansion, during which useful work is recovered from the working fluid, is halted in both of these cycles before the lowest cycle pressure is attained. Additional work could be harnessed from each such cycle if the gases were permitted to isentropically expand to the lowest cycle pressure, and thus increase overall efficiency.

In all three cycles the ideal thermal efficiency is mathematically related to the ratio of the temperature of the working fluid at the time isentropic compression

begins to the temperature of the working fluid at the time heat addition begins. The smaller this ratio, the greater the cycle efficiency. Thus, it is desirable that the working fluid be at the highest possible temperature when heat addition begins.

Unfortunately, most Brayton cycle machines such as conventional turbines, require the flow of the working fluid through the machine at substantially steady state conditions. Thus, the physical characteristics of the material utilized in constructing various parts of a Brayton cycle machine such as a turbine becomes a limiting aspect on the maximum temperature that may be employed during the cycle. Given current state of the art metallurgy, without resort to exotic cooling methods, maximum temperatures allowable in turbines are on the order of 1700°F. At temperatures appreciably in excess of 1700°F., growth due to centrifugal force may cause interference between the turbine blades and the casing and result in the destruction of the machine.

Nonetheless, Brayton cycle machines have the ability to isentropically expand the working fluid substantially down to the lowest cycle pressure and therefore provide increased efficiency in this area.

As a result of the limitations of the Otto, Diesel and Brayton cycles, proposals have been made whereby efficiencies not obtainable with any of the above-mentioned cycles can be obtained by selected use of the best characteristics of the Brayton cycle and of the Otto or Diesel cycles. Many such proposals operate on the so-called "Atkinson" cycle wherein gas expansion before exhaust occurs over a larger pressure ratio than that of the compression process.

Disclosure of the Invention

The present invention is directed to overcoming one or more of the above problems.

According to the present invention there is provided a power plant which includes a compressor for compressing an oxygen containing medium. A positive displacement combustor receives the compressed medium from the compressor and adds heat thereto under substantially constant volume conditions by the burning of fuel. Expanding means having at least first and second stages receive the heated compressed medium from the combustor and expand the medium to recover useful work therefrom and to drive the compressor and the combustor. The first stage of the expanding means is a positive displacement expander.

Other objects and advantages will become apparent from the following specification taken in connection with the accompanying drawings.

Description of the Drawings

Fig. 1 is a schematic view of a power plant made according to one embodiment of the invention; and

Fig. 2 is a pressure versus percent volume plot of the operational cycle of the power plant.

Best Mode for Carrying Out the Invention

An exemplary embodiment of the subject power plant is illustrated in Fig. 1 and is seen to include as basic components a compressor 10, a positive displacement combustor 12, a positive displacement expander 14, and a turbine 16. The expander 14 and the turbine 16 form a multiple stage expanding means.

Useful work is obtained from the power plant off from of a shaft 18 interconnecting the turbine 16 and the expander 14. Both the expander 14 and the turbine 16 extract

useful work from the working medium. A shaft shown schematically at 20 interconnects the compressor 10 and the conbustor 12 with the shaft 18. The compressor 10 and the combustor 12 are driven by the expanding means.

The basic components, as well as other components will now be addressed in detail. The compressor 10 includes an inlet 22 for receiving a working fluid. Typically, the medium will be an oxygen containing medium such as air. While not shown in Fig. 1, typically the compressor 10 will be provided with interstage cooling of a conventional nature but in any event, it is desirable that the same have a compression exponent below the theoretical isentropic value which is 1.4 for air.

The compressed working fluid exits the compressor 10 via an outlet 24 to enter a heat exchanger or recuperator 26. The recuperator 26 includes one flow path 28 receiving the compressed air from the compressor 10 and a second flow path 30 which receives expanded gas from the turbine 16 and discharges the same to atmosphere. As is well known, while the turbine 16 will typically expand the working fluid down to atmospheric pressure (or to a pressure slightly in excess of atmospheric due to ensuing flow losses in the exhaust stream), it will still be at an elevated temperature. So long as the elevated temperature is above that of the compressed air exiting the compressor 10, heat exchange will take place within the recuperator 26 with the exhaust gas heating the incoming gas to return heat to the system that would otherwise be lost. Such heat exchange is facilitated by the use of a compressor having the characteristics mentioned earlier in that the compressed air at the outlet 24 will be at relatively low temperature compared to the temperature of the exhaust gas.

The flow path 28 of the recuperator 26 extends to a receiver or surge tank 32 which may be optionally

employed in the system. When employed, it need not be separate from other components but could be combined with the recuperator 26 if desired. The purpose of the surge tank 32, as will be seen, is to smooth out pressure fluctuations that would occur due to operation of the combustor 12.

The combustor 12 is a positive displacement mechanism and is shown in Fig. 1 as a trochoidal rotary mechanism. However, it could be in the form of a slant axis rotary mechanism or a reciprocating mechanism.

In any event, it will be formed generally like any one of the mechanisms selected as the two stroke form of such mechanism as its sole purpose is to add heat to the compressed working medium under constant volume conditions. As shown in Fig. 1, heat is added by a fuel injector 36 to a working volume defined by one side 38 of a two apexed rotor 40 and that side of the housing wall 42 opposite from the single lobe 44 on the housing wall 42. At this time, the apexes of the rotor 40 preclude fluid communication with the working volume thus defined and an inlet port 46 as well as an outlet port 48.

The rotor 40 rotates and translates in the direction of an arrow 50 during operation of the combustor 12 by reason of the drive connection to the shaft 18. As shown, fuel injection and combustion is occurring at maximum volume, as opposed to minimum volume, to minimize the size of the combustor 12 required. The burning of fuel under constant volume conditions causes a pressure increase in the working medium as well as a temperature increase therein. As the rotor 40 continues to rotate, the outlet port 48 will open allowing the heated, high pressure working medium to exit the combustor 42 to flow to the positive displacement expander 14. At the same time, compressed air from the compressor 10 and the recuperator 26 will be entering the combustor 12 on the side

52 of the rotor opposite the side 38. The operation is repeated in a cyclic fashion.

The positive displacement expander 14 may be a mechanism substantially identical to the combustor 12 except that no heat addition occurs therein and the force of the expanding gas applied to the rotor 60 of the expander 14 as the gas expands is harnessed and applied to the shaft 18 as work. Again, it is not necessary that the expander 14 be a trochoidal mechanism as illustrated. It could be a slant axis rotary mechanism or a valved, two stroke reciprocating mechanism.

The purpose of the expander 14 is to recover work from the system while at the same time lowering the temperature of the working medium, through expansion, to a temperature at which the turbine 16 can safely operate. This enables considerable heat addition in the combustor to the point where the gas exiting the combustor 12 is well above the maximum operating temperature of the turbine 16 to thereby increase efficiency and power output. Generally, some form of cooling such as liquid cooling will be necessary at the inlet 62 of the expander 14 to enable the expander to function properly at the high temperatures to which the inlet 62 is continually subject.

Partially expanded gas exits the expander 14 at a port 64 and is conveyed to a receiver or surge tank 66. The purpose of the surge tank 66 again is to smooth out pressure fluctuations in gas flow which will occur by reason of the intermittent opening and closing of the port 64 by the rotor 60.

From the surge tank 66, the partially expanded gas is conveyed to the turbine 16 which may have one or more stages as desired. Preferably, in order to avoid blow down losses, the turbine 16 is provided with variable geometry to assure that its inlet pressure is equal to the pressure of the gas in the surge tank 66. For example,

by utilizing variable nozzles in the turbine 16 which are controlled, for example, by the means disclosed in the commonly assigned U. S. Patent Application Ser. No. 941,485, filed September 11, 1978, in the name of Alexander Goloff and entitled "Method and Apparatus Avoiding Blow Down Losses in Compound Engines", this may be accomplished.

In the turbine 16, working fluid is substantially fully expanded and then exhausted on a line 70 extending to the flow path 30 in the recuperator 26.

Industrial Applicability

Fig. 2 illustrates the operational cycle of the power plant for the condition wherein the positive displacement expander 14 has a 3:1 volume ratio and wherein the turbine operates on a 3:1 pressure ratio. Initial compression occurring in the compressor 10 occurs over the line AB while heat recovery in the recuperator 26 occurs over the line BC. Heat addition at constant volume occurring within the combustor 12 is shown at line CD and the temperature of the gas at peak pressure, point D, may be on the order of 2800°F., for example.

Initial expansion occurring in the expander 14 occurs from point D to point E., at which time the gas temperature will be on the order of 1700°F. Complete expansion within the turbine 16 occurs from point E to point F while heat rejection occurs from point F to point G.

Thus it can be appreciated that the power plant of the invention operates basically on the highly efficient Atkinson cycle with the further addition of recuperation to increase efficiency even more. Substantial power and improved operating efficiency are achieved in a practical application by utilizing a positive displacement expander such as the expander 14 which may be cooled much more readily than a turbine to enable high

peak pressures to exist in the system. This can be readily appreciated when one considers that if a power plant operating strictly on the Brayton cycle were employed, the cycle diagram would be represented by points ABHFA showing considerably lesser area than the cycle illustrated for the power plant defining area ABCDEFA.

Claims

1. A power plant comprising:

a compressor (10) for compressing an oxygen containing gaseous medium;

a positive displacement combustor (12) for receiving the compressed medium from the compressor and for adding heat thereto under substantially constant volume conditions by the burning of fuel; and

expanding means (14,16) having at least first and second stages for receiving the heated compressed medium from the combustor and for expanding the medium to recover useful work therefrom and to drive said compressor and said combustor, said first stage being a positive displacement expander (14).

2. The power plant of claim 1 wherein said second stage is a turbine (16) and wherein said first stage (14) expands the medium sufficiently to lower the temperature of the medium to a level not in excess of the maximum operating temperature of said turbine.

3. The power plant of claim 2 wherein said combustor (12) adds heat to said medium when said combustor (12) is at or about its maximum volume position and thereafter displaces the medium to said expanding means.

4. The power plant of claim 3 wherein a recuperator (26) interconnects said compressor (10) and said combustor (12) and means for conveying the expanded medium from said expanding means (14,16) to said recuperator (26).

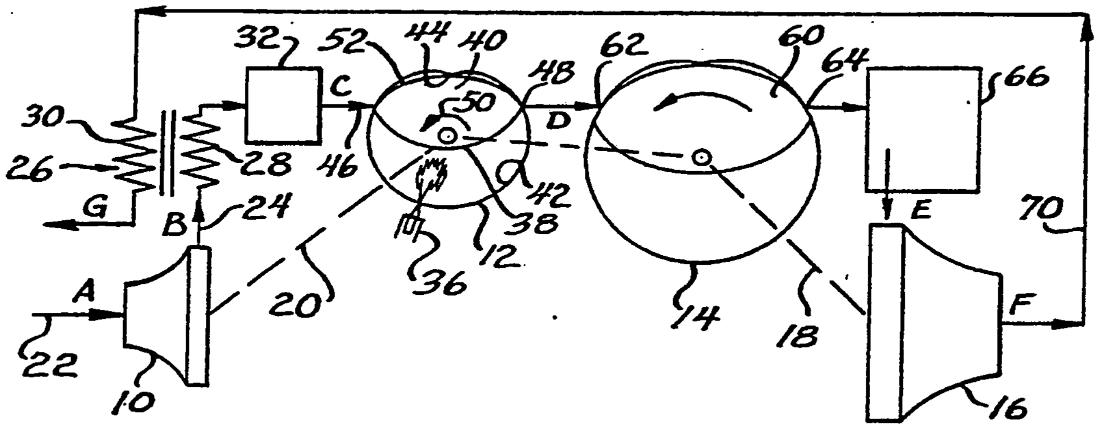

32
52
44
40
30
26
G
B
28
24
C
46
50
42
38
12
36
48
D
62
60
64
66
A
22
10
20
14
18
E
70
F
16

FIG. 1

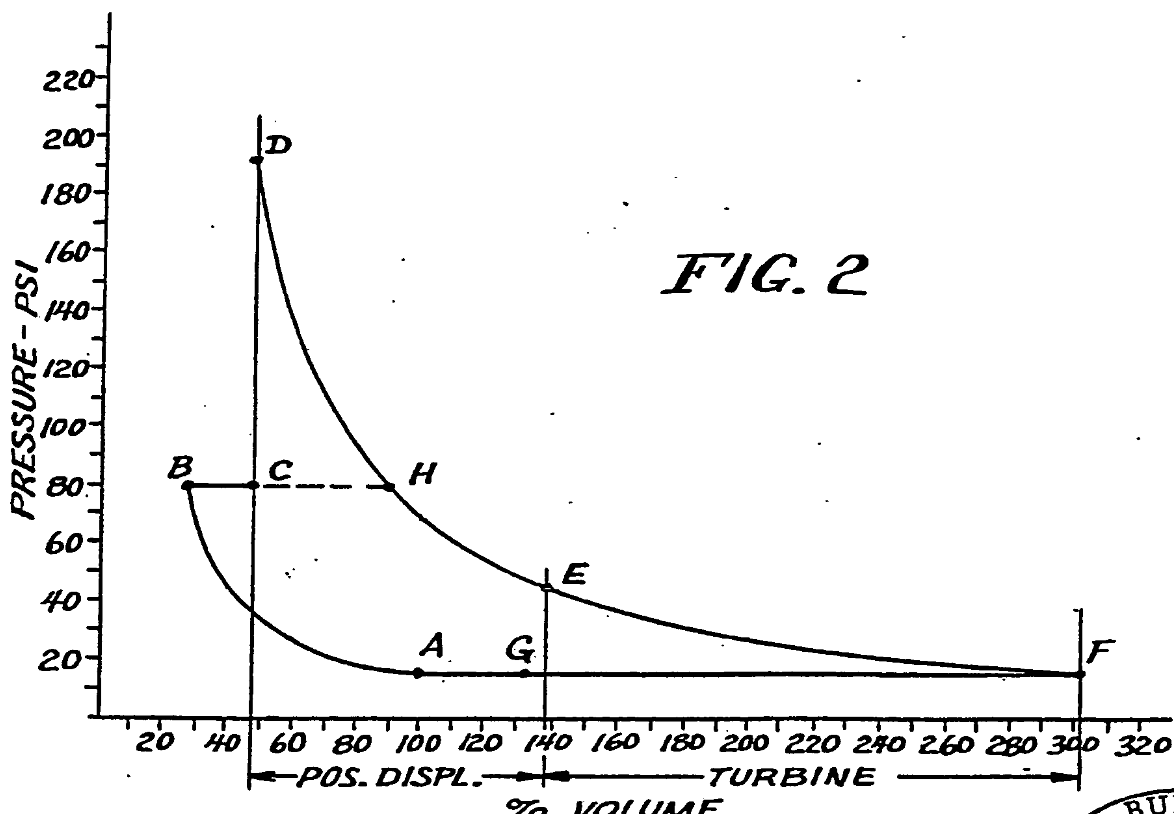

PRESSURE - PSI
220
200
180
160
140
120
100
80
60
40
20
D
B
C
H
E
A
G
F
20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320
POS. DISPL.
TURBINE
% VOLUME

FIG. 2

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 81/01337

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

Intl. Cl.[3] F02B 53/00
U.S. Cl. 123-222

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
US	123/222, 213, 215; 60/39.76, 39.78, 39.41, 39.6, 39.51R, 731, 620,623

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
A	US,A, 1,332,427, Published 02 March 1920 Cooper	1-4
A	US,A, 3,417,564, Published 24 Dec. 1968 Call	1-4
A	US,A, 4,241,576, Published 30 Dec. 1980 Gertz	1-4
A	DE,A, 2,426,700, Published 11 Dec. 1975 Dunas	1-4
A	US,A, 3,222,864, Published 14 Dec. 1965 Dyste et al	4

* Special categories of cited documents: [15]

"A" document defining the general state of the art

"E" earlier document but published on or after the international filing date

"L" document cited for special reason other than those referred to in the other categories

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but on or after the priority date claimed

"T" later document published on or after the international filing date or priority date and not in conflict with the application, but cited to understand the principle or theory underlying the invention

"X" document of particular relevance

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
15 December 1981	07 JAN 1982
International Searching Authority [1]	**Signature of Authorized Officer [20]**
ISA/US	Michael Koczo, Jr. MICHAEL KOCZO, JR.

Form PCT/ISA/210 (second sheet) (October 1977)